1J1-4

Acoustic picker by hemispherical ultrasonic transducer array and phase control using low-reflection stage

低反射ステージを用いた半球状超音波アレイと位相制御による音響ピッカー

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1. Introduction

Acoustic radiation force has been studied for a long time [1]. Typically, langevin-type transducers and ultrasonic transducers array has been used to create high power sound pressure enough to move objects [2].

As an applied research using ultrasonic transducers array, manipulating particles by phase control of the arrays and ultrasound tactile display are reported [3][4][5].

In this research, we examined the feasibility of the ultrasonic transducers array-based acoustic picker (acoustic picking up) which can non-contact pick up a particle on a stage.

2. Equation of acoustic radiation force

When a spherical particle smaller than a wave length is put in the sound field, the acoustic radiation force on the particle is represented by gradient of an acoustic potential U,

$$F = -\nabla U, \tag{1}$$

$$U = V[f_1 \frac{1}{2}\kappa_0 \langle p^2 \rangle - f_2 \frac{3}{4}\rho_0 \langle v^2 \rangle] \tag{2}$$

where V indicates the particle volume, p is the sound pressure, v is the particle velocity, κ_0, ρ_0 indicates compressibility and density of air, $\langle \cdot \rangle$ denotes the time average. f_1 and f_2 are defined as

$$f_1 = 1 - \frac{\kappa_p}{\kappa_0}, f_2 = \frac{2(\rho_p - \rho_0)}{2\rho_p + \rho_0} \tag{3}$$

where κ, ρ indicates compressibility and density, subscripts 0 and p in equations denotes medium and the particle, respectively.

3. Hemispherical ultrasonic transducers array

We designed and made the hemispherical ultrasonic-focusing device which can create high sound pressure.

3.1 Design

The diameter of the device is 10 cm and 80 ultrasonic transducers are mounted facing the center of the hemisphere. Hemispherical array can create high sound pressure at the focal point (center of the hemisphere).

The diameter of the ultrasonic transducer is 1 cm, the center frequency is 40 kHz, and the driving voltage is 20 Vp-p. The device and the model diagram are shown in **Fig.1**. This device can output a sound wave with different phase as shown in **Fig.1** (right), where $\hat{\theta}$ indicates phase inversion of θ ($\hat{\theta} = \theta - \pi$).

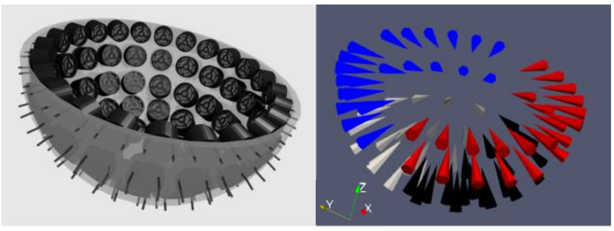

Fig. 1 Hemispherical ultrasonic transducers array

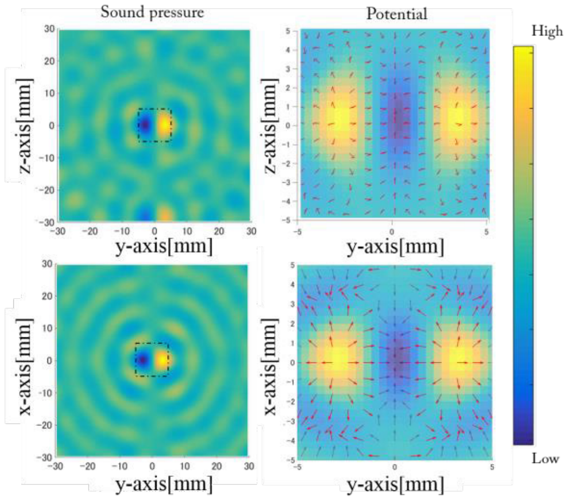

Fig. 2 Sound pressure distribution and potential

3.2 Particle movement

Fig.2 shows the simulation of sound pressure distribution and acoustic potential of a certain time with $\phi = 0$. The focal point is $(x, y, z) = (0,0,0)$ (i.e., center of the hemisphere). The range of acoustic potential in the right figure is the dotted line zone in the left figure. The direction of the arrows in the right figure means the direction of acoustic radiation force that particle receives. As the arrows indicate, a particle placed near the focal point receives acoustic radiation force toward the focal point and levitates at the position balanced with gravity.

4. Acoustic picker

We examined non-contact picking up for a particle by phase control of the hemispherical ultrasonic transducers array.

4.1 Method

As ϕ shifts while fixing θ, the high sound pressure zone will shift up or down. A particle can be levitated and moved by this method. A particle can be moved up to about the wavelength (≈ 8.5mm) from the horizontal plane of the hemisphere.

When applying this method to a particle on a solid stage, sound pressure distribution in the hemisphere will be distorted by effect of reflection from the stage. Accordingly, we propose the method using metal mesh as a stage to reduce the reflection from a stage.

4.2 Experiment

To examine the feasibility of acoustic picker, we experimented using polystyrene spheres with a diameter of 1mm and 3mm as a particle to pick up. **Fig.4** shows the outline of the experiment, where *d* indicates the distance between the device and the stage. We shift the phase ϕ from 0 to 360 [deg] while keeping the distance *d* away.

4.3 Result

1 mm and 3 mm spheres could be picked up. Distance *d* in which can pick up the spheres was 0.0 to 18 mm. **Fig.4** shows the time-sequence photos of the experiment when distance *d* was 18 mm. And sound pressure distribution (time average of a sound amplitude) on the *yz*-plane at *x*=0 corresponding to **Fig.4** is shown in **Fig.5**. The arrows indicate the position and the direction of ultrasonic transducers. The colors of the arrows represent the phase as **Fig.1.** In scene 1, the input to the device is off.

5. Conclusion

In this research, we create a high-power sound field at focal zone using hemispherical ultrasonic transducers array and confirmed the levitated particle can be shifted up and down by phase control of sound wave.

Then, applying this method to the particles on the metal mesh stage, we successfully developed the non-contact picking up by acoustic pressure. As the next step, we will examine and control the effect of stage for robust acoustic picking up.

References

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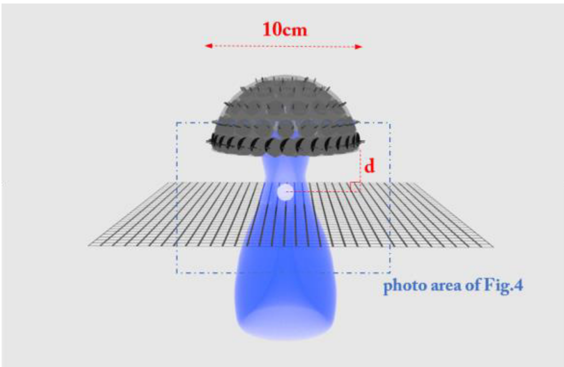

Fig. 3 Outline of the experiment

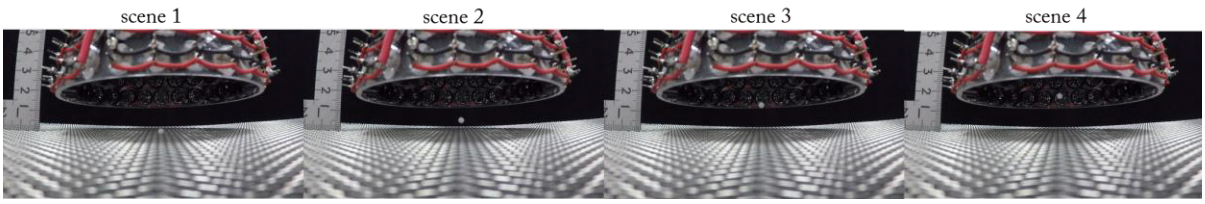

Fig. 4 Acoustic picking up by phase control

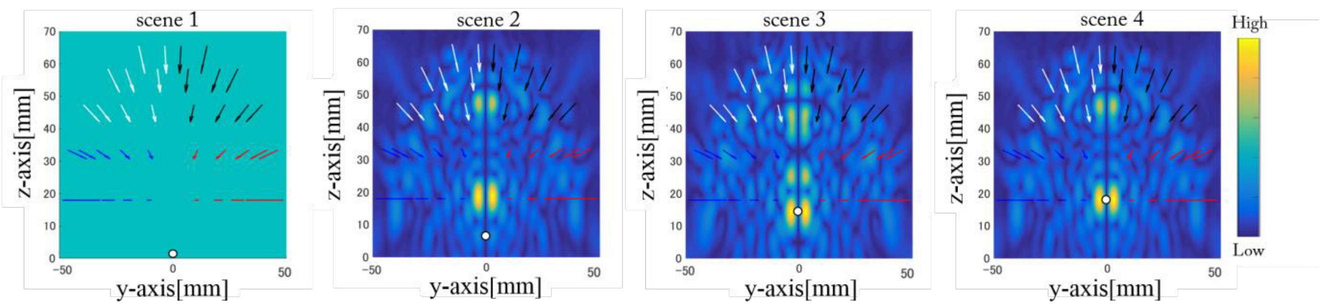

Fig. 5 Time average of sound pressure